GEOLOGY OF THE MOUNT WASHINGTON
7.5-MINUTE QUADRANGLE,
BERNALILLO AND VALENCIA COUNTIES, NEW MEXICO

by

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Geologic mapping by strata and Phanerozoic structures
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CONTENTS

INTRODUCTION

The Mount Washington 7.5-minute quadrangle comprises an area of about 158 km^2 (61 mi^2) along the western flank of the Manzanita Mountains, in Bernalillo and Valencia Counties, New Mexico (Fig. 1). The quadrangle is approximately 15 km (10 mi) east of the Pueblo of Isleta and about 19 km (12 mi) southeast of the Albuquerque Civic Center. The quadrangle lies within the Pueblo of Isleta, Kirtland Airforce Base (KAFB) and Sandia National Laboratories (SNL). Earlier studies of the Manzanita Mountains were done by Reiche (1949) and Myers and McKay (1970 and 1976). Several unpublished studies have refined the stratigraphy, structure and geomorphology of portions of the quadrangle area (Thomas et al., 1995; Cavin, 1985; Parchman, 1981). The geologic map (Plate I) is the result of additional detailed field mapping and integration of previous work that has refined the structure and stratigraphy of the western flank of the Manzanita Mountains and the eastern margin of the Albuquerque basin.

Geologic mapping was completed in cooperation with the University of New Mexico (UNM) and the New Mexico Bureau of Mines and Mineral Resources (NMBMMR). The topographic base for the geologic map is the Mount Washington quadrangle, 7.5-minute topographic series, published by the United States Geological Survey at a scale of 1:24,000 (one inch equals 2000 feet). Proterozoic rocks and structures were mapped at a scale of 1:12,000 and compiled onto the geologic map at 1:24,000 (Plate I). Paleozoic rocks and associated structures were mapped in reconnaissance, with some modifications after Myers and McKay (1970; scale 1:24,000). Numerous observations of slip relationships were made on faults cutting the Paleozoic rocks. Piedmont deposits were delineated and compiled at a scale of 1:24,000. Compilation of data from various sources (Fig. 2) and scales of mapping onto the geologic map resulted in significant variations in the apparent precision of mapping across the study area; therefore, differences in map detail are inevitable.

Principal contributions and revisions to previous work (Reiche, 1949; Myers and McKay, 1971; Kelley, 1977; Cavin, 1985; Parchman, 1981; and Thomas et al., 1995) include: refinement of the stratigraphy structure and metamorphic and plutonic history of the Manzanita Mountains; differentiation of the piedmont stratigraphy on the Isleta Reservation; recognition of range-bounding structures (see Myers and McKay, 1970); and incorporation of subsurface data (Table 1).

The quadrangle map has been placed on open file in order to make it available to the public as soon as possible. The map has not been reviewed according to New Mexico Bureau of Mines and Mineral Resources standards. Revision of the map is likely because of the on-going nature of work in the region. ***The contents of the report and map should not be considered final and complete until it is published by the New Mexico Bureau of Mines and Mineral Resources.***

Comments to Map Users

A geologic map graphically displays information on the distribution, nature, orientation and age relationships of rock and surficial units and the occurrence of structural features (Bates and Jackson, 1987). Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on the Mount Washington quadrangle geologic map are based on reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist. Significant portions of the study area were mapped at scales smaller than depicted on the geologic map; therefore, the user should be aware of significant variations in map detail. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown everywhere.

Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. The information provided on this map cannot be substituted for site-specific geologic, hydrogeologic or geotechnical investigations. The use of this map to precisely locate buildings relative to the geological substrate is **not** recommended without site-specific studies conducted by qualified earth-science professionals.

Accessibility

The Mount Washington quadrangle lies within the northeastern part of the Isleta Indian Reservation and southeastern sector of the Sandia Military Reservation (KAFB & SNL); travel within KAFB, SNL and Isleta Reservation is prohibited or locally restricted. The area is not accessible by public roads; however, several graded dirt and paved roads allow access to portions of the study area. The eastern half lies within the Manzanita Mountains and has very limited road access.

Geologic and Physiographic Setting

The quadrangle traverses the western flank of the Manzanita Mountains and the eastern margin of the Albuquerque basin (Kelley, 1977). The quadrangle lies south and east of the Tijeras and Hubbell Springs fault zones. The mountain-front, north of Hell's Canyon, is deeply embayed. The western half of the quadrangle forms a deeply to moderately dissected west-sloping piedmont. Several inselbergs of Proterozoic and inliers of Pennsylvanian rocks mark the northeastern part of the piedmont. Topography is generally steep and rugged in upland areas, which are held up by resistant Pennsylvanian sedimentary and Proterozoic crystalline rocks. Tertiary and Quaternary deposits are exposed along valley floors and in the piedmont. The study area exhibits 833 m (2734 ft) of maximum topographic relief, with a maximum elevation of 2434 m (7988 ft) at the Manzano Lookout Tower near the northeast corner, and a minimum elevation of approximately 1719 m (5640 ft) near Cañon de Sanchez along the southwestern corner of quadrangle. Maximum piedmont relief is about 135 to 170 m (440 to 560 ft). Relief along the mountain-front escarpment ranges between about 91 to 582 m (300 to 1910 ft).

STRATIGRAPHY

All map units are described in Table 3 (p. 26). The age and stratigraphic relationships of these map units are summarized in the Correlation of Map Units (p. 45).

Quaternary and Pliocene Deposits

Alluvial Deposits

Quaternary and Pliocene alluvial deposits of the Mount Washington 7.5-minute quadrangle contain variable proportions of gravel, sand and silt, deposited by intermittent and ephemeral streams; mass-movement deposits typically occur on hill slopes. Map-unit differentiation is based on stratigraphic position (inset or depositional relations), surface morphology, degree of soil-profile development (see Gile et al., 1966; 1981) and sedimentary character. Deposits are a mixture of poorly sorted, poorly to moderately stratified, clast- and matrix-supported alluvium, having predominantly gravelly to sandy textures; silt-clay textures are locally common. Clast constituents typically reflect bedrock composition of local upland drainage systems associated with the western flank of the Manzanita Mountains. Alluvial deposits are 12- to 21-m thick and unconformably overlie Mesozoic and older rocks. Detailed soil-profile descriptions were not made during this study, therefore, unit subdivisions (i.e., Qvm1 or Qvm2) may not be correlative across individual drainage basins. Alluvial deposits are divided into three major classes: 1) valley-fill alluvium, 2) piedmont-slope alluvium, and 3) colluvium and spring deposits. General characteristics of these classes are:

1) *Valley-fill alluvium (Qv subunits)* — Stream (floodplain, fill-terrace) deposits are restricted to major entrenched valleys and tributaries, such as Hell's Canyon Wash, Cañada Colorada and Cañon de Sanchez. Units typically have an elongated planform shape and are differentiated on the basis of inset relationships and surface morphology;

2) *Piedmont-slope alluvium (Qp subunits)* — Stream and alluvial-fan deposits on constructional and erosional parts of piedmont slopes. Units include fan and

debris-flow deposits and shallow-valley fills that are not graded to major entrenched arroyo systems;

3) *Colluvium and spring deposits (Qca and QTr subunits)* — Mass-movement deposits and calcareous spring recognized in upland regions and valleys.

The Pliocene and Quaternary alluvial sequence, as discussed in this report, is a sequence of stepped piedmont and valley-fill and valley-border landforms, deposits and geomorphic surfaces that unconformably overlie lower(?) Tertiary and older rocks. Members of this sequence range from historical to Pliocene in age and are informally defined, mapped and correlated on the basis of stratigraphic superposition, surface morphology, landscape-topographic position, and to a limited extent, soil-profile characteristics.

Deposits are a mixture of poorly sorted, poorly to moderately stratified, clast- and matrix-supported alluvium having predominantly gravelly and sandy textures. Details of deposit character are discussed in the Description of Map Units (Table 3) section accompanying the geologic map. Tentative correlations to previous studies are listed on Table 2. These deposits record episodes of deep valley entrenchment and partial backfilling that are graded to the Llano de Manzano and to former base levels on the footwall of the Hubbell Springs fault zone. Alluvial deposits range from 12 to 21 m in thickness and overlie Madera, Yeso and Abo Formations (Table 1). Clast lithology reflects composition of older units exposed within local upland drainage-basins. Upland regions are dominated by erosion with only local, short-term sediment storage on hillslopes and valley floors. Mass-movement deposits are common on hillslopes; hyperconcentrated-flow, debris-flow and local stream-flow deposits occur in higher order drainages. Piedmont-slope deposits extend westward from the mountain front and form constructional landforms on coalescent piedmont alluvial-fan complexes. Colluvium is common along unit margins and on terrace risers associated with major drainages. Valley-floor deposits occupy former floodplain positions of major drainages.

Unit QTspc is topographically the highest unit on the piedmont and unconformably overlies Paleozoic and Mesozoic rocks (Tables 1 and 2). This unit is poorly exposed and contains well-indurated, limestone-rich conglomerate with minor sandstone interbeds preserved on the footwall of the Hubbell Springs and Sanchez fault zones. The top of unit QTspc forms a fairly broad constructional summit surface that exhibits a partially stripped petrocalcic soil with stage IV to V pedogenic calcium-carbonate morphology. This unit locally forms two inset deposits or straths that sit between 11- to 30-m above present valley floors in the study area (Fig. 3). The top of QTspc1 sits about 52 m above the floor of the Llano de Manzano in the adjacent Hubbell Spring quadrangle, where the escarpment of the Hubbell Bench is deeply embayed, exhibits a sinuosity of about 3.7, and has retreated about 640 m to the east. The magnitude of hillslope retreat and strong soil development suggests that QTspc is probably at least Pliocene in age and is therefore correlated to the Santa Fe Group.

Unit QTpo is inset against QTspc and mapped as rounded inliers north of Cañada Colorada. This unit is poorly exposed and occurs along the western edge of the quadrangle where it is physically correlated with unit Tf2 in the Hubbell Springs quadrangle (Love et al., 1996).

Unit Qpo is inset against QTspc and QTpo and forms rounded hills, whose summits are between 5- to 10-m above local base level. This unit is poorly exposed, but exhibits stage III calcium-carbonate morphology and locally, multiple buried soils, indicating episodic aggradation. This unit is locally divided into three subunits of the basis of inset relations. Unit Qvo is correlative to Qpo and is associated with the early incision of the Hells Canyon Wash and Cañada Colorada stream systems.

Unit Qvm forms broad valley-fill deposits that are inset against Qpo. This unit forms prominent terraces along the margins of Hell's Creek Wash, Cañon de Sanchez and Cañada Colorada and associated tributary systems. This unit sits between 3.5 and 8.5 m above local base level in the study area. This unit is locally buried by deposits of unit Qvy. Deposits contain conglomerate and minor sandstone and exhibit stage III calcium-carbonate morphology with multiple calcic (Bk) horizons within Hell's Creek Wash. Unit Qvm is locally divided into two subunits on the basis of inset relations.

Unit Qvy is inset against Qvm and forms sandy to conglomeratic valley-fill deposits that are at least 4 m in thickness. Light-gray clayey carbonate and distinct (high-chroma) orange-brown mottles are common along reaches within Colorada Canyon and may be related to fluctuating water levels perched above well cemented Santa Fe Group deposits. Deposits were drained as the streams continued to incise into their modern valleys. Because of its position on valley floors, the soils are rather complicated, ranging from weakly developed (weak stage I carbonate morphology) and locally possessing multiple buried Bk horizons with stage II and III morphology. This unit forms a late Pleistocene to Holocene valley fill that is locally buried or incised by historic and late Holocene streams.

Pediment gravels were not observed in the study area; however two inliers of Madera

Formation flanking the mouth of Hell's Canyon slope to the west at angles less than bedding dips. In particular, a prominent inlier north of the creek projects beneath QTspc2 and may be the exhumed surface of erosion (ie. pediment) that underlies piedmont deposits of the Santa Fe Group.

Paleozoic Rocks

Upper Paleozoic strata within the quadrangle, both exposed and concealed (Table 1), include the Sandia Formation, Madera Group (lower and upper), Abo Formation and Yeso Formation. They represent marine and non-marine sedimentary deposits of Pennsylvanian and Permian age. For a description of these units see Table 3.

Upper Paleozoic strata of Mississippian to Permian age in the New Mexico region were deposited in and adjacent to widespread shallow seaways. These widespread syntectonic basins may have formed during collision of the South and North American continents in the region that now includes Texas and Oklahoma (Kluth and Coney, 1981). Alternatively they may have formed during collision of island arcs along the SW margin of the continent in the region of northern Mexico (Royden et al., 1996).

Proterozoic Rocks

Early Proterozoic rocks in the Mount Washington quadrangle consist of ductiley deformed and metamorphosed volcanic, sedimentary and plutonic rocks. These rocks generally formed in volcanic arcs and related arc basins along the growing southern periphery of cratonic North America in the Early Proterozoic (ca. 1.6–1.7 Ga). The complex metamorphic sequence is described in Table 3. The metavolcanic and metasedimentary succession is probably equivalent to rocks dated at 1680 Ma in the southern Manzano Mountains (Bauer et al., 1993). They are intruded by various units, most notably the Manzanita Granite dated at 1632 ± 45 Ma by the U-Pb zircon method (Unrue, unpublished data). A non-metamorphosed granitic to rhyolitic dike (Ygd, Table 3) is here confirmed to be of middle Proterozoic age (1428 ± 3.6 Ma) on the basis of a new $^{40}Ar/^{39}Ar$ plateau age from muscovite (New Mexico Geochronology Research Laboratory; M. Heizler, written commun. 1997). This east-trending dike cuts metasedimentary rocks about 2 km northwest of the mouth of Hells Canyon.

Mapping in this quadrangle has led to a new proposed stratigraphy for the Sandia-Manzano uplift. This proposed stratigraphy is based on correlation of similar lithologies across major folds and thrusts, so the stratigraphic interpretation is strongly based on the accompanying structural interpretation. In particular, we have correlated mafic to intermediate metavolcanic packages (Xmv and Xiv) that have been variously named (from north to south) the Tijeras (Connolly 1982), Coyote (Cavin, 1985), and Isleta (Parchman, 1981) greenstones. These units all contain a heterogeneous assemblage of metavolcanic and volcaniclastic units and all appear to grade upwards into phyllites (Xp) and dirty lithic arenites (Xla). The more mature quartzites (Xq) and schist (Xs) of the northern part of the quadrangle probably overlies the lithic arenite as part of a trend towards more mature sediments, but contacts are not exposed in this quadrangle.

A diverse assemblage of intrusive units are present in the Mount Washington quadrangle. Units within the greenstone include mafic intrusives (Xmi), diorite (Xd), and biotite-bearing granite (Xbg) that all may be part of an intrusive suite related to the nearby Ojito pluton to the south and the Cibola granite to the north. The latter has been dated as 1653 ± 21 Ma by Unrue (unpublished data). The Manzanita Granite (Xmg) forms a major plutonic complex in the northern part of the quadrangle; it has yielded a U-Pb zircon date of 1632 ± 45 Ma (Unrue, unpublished data). It is intruded by leucocratic granite, aplite, and pegmatites that may be evolved units of the same intrusive event. A series of quartz veins (Xqv) intrudes along the main foliation throughout the central part of the quadrangle. A single dike of fine grained granite (Ygd) intrudes along foliation in the northern part of the quadrangle; this dike yields a $^{40}Ar/^{39}Ar$ date on muscovite of 1428 ± 3.6 Ga.

STRUCTURAL GEOLOGY

Folds, faults and shear zones in the Mount Washington quadrangle exhibit several styles of deformation related to different periods of tectonic activity since the Proterozoic. This section discusses some of the recent refinements to the structure of the study area.

The range-front and intra-basinal faults are buried by Pliocene basin-fill and younger deposits in the study area. The Coyote fault, named by Myers and McKay (1971), is a north-striking high-angle fault (most recent movement probably normal) that juxtaposes Sandia and Madera Formations down-to-the-west against Proterozoic crystalline rocks between Coyote Canyon and the northern boundary of the Isleta Reservation. This frontal fault is associated with a deeply dissected west-facing escarpment, north of the projected trace of the Colorada fault. The Colorada fault is a structure named by Kelley (1977) for a northwest-striking fault along the Cañada Colorada drainage. The Colorada fault is poorlly known with respect to sense of shear; it displaces Madera Formation against Proterozoic crystalline rocks along a northwest trending mountain-front reentrant at the mouth of Hells Canyon. The northwestward projection of this structure is also recognized in the subsurface by an abrupt southward thickening of basin fill, just west of the study area (Thomas et al., 1995). The Manzanita fault, which lies between Hells Canyon and Seis Canyon, is a continuation of the north-trending Manzano fault. The Manzanita fault probably represents a Laramide transpressional fault reactivated by late Cenozoic rifting. The Hells Canyon fault, of late Paleozoic character (ie. sinistral) also may have been reactivated by Laramide deformation.

The Sanchez fault is here named for a northwest trending escarpment along the southeastern corner of the Hubbell Springs quadrangle (see Love et al., 1996). This fault is subparallel to the Colorada fault and displaces QTpsc down to the southwest. This structure is buried by Qvm in the study area; however, the fault trace projects towards a major mountain-front reentrant at Seis Canyon, just south of the study area, where it probably connects to the Manzano Mountains frontal fault system. Newly named northerly trending faults displacing Pennsylvanian rocks include the Torre, Malacate, Tiro, Sol Mete, Cueva and Puerta faults. Many of these faults appear to have complex slip histories, as described below.

Paleozoic and Younger Structures

Paleozoic and younger structures consist primarily of faults and gentle- to steep-limbed drape or drag folds adjacent to these faults. Most faults trend NNE; less common and shorter fault segments locally trend NW, NNW and ENE. Reiche (1949) recognized strike slip, reverse and normal faults in the Manzanita Mountains area. New mapping for this report suggests a complex slip history for many faults in the Mount Washington Quadrangle. Several faults, namely the Malacate, Torre and Hells Canyon, show an early history of sinistral strike slip probably associated with Ancestral Rocky Mountains deformation in late Paleozoic time. Sinistral slip on these NNE trending faults is generally indicated by NNW striking releasing bends and ENE striking constraining bends (reverse faults), in addition to *local* preservation of subhorizontal striations on high-angle fault surfaces.

Constraining bends, one observation of subhorizontal striations, and en echelon folds along the Hells Canyon fault (near Gotera Canyon) clearly represent an early period of sinistral transpression. Reidel like splays from the Hells Canyon fault may also represent a period of Laramide right lateral transpression. The northern portion of the Hells Canyon fault (and other local segments) exhibits dip-slip normal displacement, which may represent later reactivation by late Cenozoic rifting. It could also represent second-order transtensional forces of Laramide origin.

Local thickness variations and facies relationships in the Sandia Formation strongly suggest that segments of the Torre and Cueva faults, which locally display normal slip, were active in Middle Pennsylvanian time. The Sandia is anomalously thick (approx. 180 m), dominantly conglomeratic, and distinctly tilted in the hanging wall block of the Torre fault north of the HERTF site. Dips of the Pennsylvanian beds locally decrease upsection here, which implies contemporaneous westward tilting of the block. At the Cueva fault, the Sandia Formation appears to thicken abruptly from approximately 80 feet (24 m), to greater than 120 feet (36 m) on the southwestern downthrown-block. On the upthrown northern block the

Sandia is mostly conglomeratic, whereas on the southern depressed side, shales and shell-rich limestones are prevalent. The latter presumably reflect greater water depths and lower energy depositional environments on the downthrown block. Sparry, calcite-filled cavernous blocks of tilted limestone locally occupy a narrow graben developed in the overlying Madera limestone adjacent to the Cueva footwall block. Another limestone bed at the ridge crest appears to be unfaulted where it overlies the projected trace of the Cueva fault. The Cueva fault could represent a releasing-bend-type splay from the projected trend of the sinistral Malacate fault.

Echelon folds and one minor dextral slip fault adjacent to the Manzanita fault suggest an earlier period of right-lateral transpression, presumably Laramide, along this range bounding fault. The Tiro fault locally shows a minor zone of right-slip within a complex hanging wall zone; however this fault appears to be dominated by later down-to-the-west, dip-slip normal displacement, of probable late Cenozoic age.

Major, down-to-the-west, range-bounding structures most likely represent dip-slip normal faults associated with spreading along the Rio Grande rift in middle to late Cenozoic time. Examples are the Coyote, Colorada and Manzanita faults. Extension (gravitational collapse) along the rift may have removed earlier components of crustal shortening (reverse faulting) from many of these preexisting fault zones of Laramide and late Paleozoic ancestry. For instance, the down-to-the-east EOD reverse(?) fault may represent an unextended section of the down-to-the-west Hubbell Springs fault trend, which lies directly southwest of the EOD fault. The Hubbell Springs fault zone shows evidence of Pliocene to Pleistocene normal displacement associated with extension along the Rio Grande rift; the EOD fault does not show indications of Cenozoic displacement.

No clear evidence of Quaternary faulting was found in the Mount Washington quadrangle. However, warping and displacement along the range bounding faults has probably influenced the distribution and thickness of Pliocene alluvial deposits (eg. QTspc) in the western portion of the quadrangle (Table 1).

Minor thrust faults are widely observed in Paleozoic quartzites and limestones within the quadrangle. These minor contractional faults suggest incipient thin-skinned shortening in an easterly (ENE to ESE) direction. They may have been associated with a Laramide transpressional highland now engulfed by the Rio Grande rift. An ENE striking segment of the Torre fault, which defines a sinistral thrust fault, most likely represents NNW directed shortening in late Paleozoic time. Small fluorite and quartz veins in Paleozoic and Precambrian rocks may represent local tensional zones adjacent to strike-slip faults of late Paleozoic and/or Laramide ancestry.

Proterozoic Structures

The character of Proterozoic structures is illustrated in the accompanying cross section (Plate II). Metamorphic and plutonic rocks are ductilely deformed and show evidence for multiple generations of deformation. The main tectonic fabric is a penetrative foliation (Sl) that strikes northeast and dips moderately, 30°–70° towards the southeast. The major structures of this generation in a north to south cross section are as follows.

1) The Vincent Moore shear zone (named the Vincent Moore thrust by Cavin, 1985) is a low angle shear zone that is mainly exposed in the Tijeras Quadrangle to the

north. In the north, it places clean quartzites (Xq) over mafic volcanic rocks of the Tijeras greenstone; in the south it places quartzite over granites that resemble the Cibola granite of the Tijeras Quadrangle, dated by U-Pb zircon as 1653 ± 21 Ma (Unrue, unpublished data). This thrust dips south, under the Mount Washington quadrangle, and shows top-to-the north shear sense in mylonitic rock. Phyllonite from the zone yielded a whole-rock $^{40}Ar/^{39}Ar$ date of 1423 ± 2 Ma (Karlstrom et al., 1997), which is interpreted to be time of reactivation of an earlier shear zone during 1.4 Ga tectonism in the aureole of the Sandia pluton (Kirby et al., 1995). This structure is considered here to be the frontal thrust of the Manzanita thrust system, described below.

2) The Coyote Creek synclinorium is an asymmetrical, north-verging synclinorium involving rock units Xq and Xs. These folds are apparently truncated by thrust-sense shear zones on the Manzanita shear zone.

3) The Manzanita shear zone is a new name proposed for the 2–4 km wide shear zone in the northern part of the Mount Washington quadrangle. This zone includes the Coyote "thrust" of Cavin (1985), but is a wide zone of distributed deformation rather than a discrete thrust. This zone forms the tectonized intrusive contact between greenstones (named the Coyote greenstone by Cavin, 1985) and the Manzanita Granite. Intrusive relationships are suggested by the complex interfingering of granite and greenstone, but the zone contains an impressive array of mylonitic and ultamylonitic rock. Units mapped by Cavin (1985) as metarhyolite are interpreted here to be ultamylonitic Manzanita Granite based on preserved feldspar porphyroclasts of

similar size to the megacrysts in the Manzanita Granite. The southern edge of the Manzanita shear zone is not well defined, as shearing decreases southward into the pluton. Shearing is top-to-the-north based on abundant kinematic indicators such as shear bands, S-C fabric, and porphyroclast systems. Early shearing took place at temperatures in excess of 500°C based on ductiley deformed feldspar porphyroclasts, and continued at lower temperatures based on low- to moderate- temperature quartz microstructures such as core and mantle structure and ribboned quartz. We interpret these features to indicate that top-to-the-north shearing took place as the pluton was being emplaced and subsequently cooled to ambient (green schist-grade) conditions. This dates development of the Manzanita thrust system as Early Proterozoic, about 1630 Ma.

4) The Isleta shear zone (Isleta thrust of Parchman, 1981) is a wide zone of shearing near the south margin of the Manzanita Granite. Like the Manzanita shear zone, this zone also grades into less deformed plutonic rock, shows kinematic evidence for top-to-the-north shear, and represents a syn-plutonic shear zone that modified the original intrusive contact. Evidence that the zone represents the margin of the pluton comes from the contact aureole preserved in the adjacent country rock defined by sillimanite, and andalusite isograds that are generally parallel to the shear zone and the pluton margin.

5) A major synclinorium–anticlinorium pair occurs in the southern part of the quadrangle. The synclinorium is defined on the basis of opposing graded bedding indicators in the lithic sandstone unit (Xla) and by repetition of a distinctive chert

marker layer. The anticlinorium, here named the Hells Canyon anticlinorium, was mapped by Parchman (1981) based on repetition of a distinctive dacitic tuff unit (Xdt) both north and south of Hells Canyon. Units in these folds are strongly transposed parallel to the northeast-striking axial plane (Sl) of the folds. Based on frequently-seen thrust belt geometries, the cross section suggests that the synclinorium overlies a flat, and the anticlinorium overlies a ramp in the Manzanita thrust system.

A second generation of ductile structures occurs as variably-developed, but often weakly expressed crenulations of the main foliation. The axial plane crenulation cleavage strikes northwest and is subvertical; crenulation fold axes plunge southeast. Timing of formation of these structures could be either Early or Middle Proterozoic.

HYDROGEOLOGIC FRAMEWORK

Water well data within the Mount Washington sector of the Isleta Reservation indicate very thin basin fill, much of which is above the water table. These wells are completed within Permian strata (Table 1) and are adequate for limited pumping for livestock. The Hells Canyon drainage is the largest drainage basin in the Manzanita Mountains, about 103 km^2 (39 mi^2) in area. It represents a significant local source of mountain-front recharge into the basin aquifer system, especially where the stream crosses the Sanchez fault.

Coyote Spring occurs where the generally westward groundwater flow is blocked by relatively impermeable shales of the Sandia Formation, which is juxtaposed against fractured crystalline basement rocks. Other springs in the quadrangle also appear to be fault controlled.

Dense pine forest above 7000 feet elevation (ca. 2100 m) and some lower north-facing slopes generally represent areas of more significant precipitation and potential groundwater recharge. All surface drainages lead into the eastern flank of the Albuquerque Basin, and presumably most of the groundwater moves in that direction. However, some ground may move along the regional NNE dip toward the Tijeras fault and the Estancia Basin. Permeability in well indurated Paleozoic and Precambrian rocks is most likely associated with fractures. Uncemented (ie. younger) fault breccias may be the most significant pathways of groundwater flow in these older rocks. Pliocene and Pleistocene paleovalley fills, locally entrenched into down faulted blocks along the western margin of the quadrangle, could represent significant, but difficult to locate, local aquifers. Temperature regimes and flow paths of shallow groundwater in the Kirtland sector of the Mount Washington quadrangle are currently being studied by Marshall Reiter (Prin. Sr. Geophysicist) at the New Mexico Bureau of Mines and Mineral Resources.

GEOLOGIC HAZARDS

Potential geologic hazards in the Mount Washington quadrangle include earthquakes, flooding along entrenched drainages, and landsliding or slumping on steep mountain slopes underlain by shales (eg. upper Sandia Formation). Quaternary normal faults along the Rio Grande Rift represent a potential regional earthquake risk. All high-angle faults and range boundary faults mapped in the Mount Washington quadrangle should be considered capable of normal slip in the regional extensional stress domain of the rift. However, there is no indication of Holocene or Pleistocene displacement of any fault within the quadrangle. Mapped faults in adjacent quadrangles do show signs of Quaternary movement, so the threat facing slopes generally represent areas of more significant precipitation and potential groundwater recharge. All surface drainages lead into the eastern flank of the Albuquerque Basin, and presumably most of the groundwater moves in that direction. However, some groundwater may move along the regional NNE dip toward the Tijeras fault and the Estancia Basin. Permeability in well indurated Paleozoic and Precambrian rocks is most likely associated with fractures. Uncemented (ie. younger) fault breccias may be the most significant pathways of groundwater flow in these older rocks. Pliocene and Pleistocene paleovalley fills, locally entrenched into down faulted blocks along the western margin of the quadrangle, could represent significant, but difficult to locate, local aquifers. Temperature regimes and flow paths of shallow groundwater in the Kirtland sector of the Mount Washington quadrangle are currently being studied by Marshall Reiter (Prin. Sr. Geophysicist) at the New Mexico Bureau of Mines and Mineral Resources.

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Potential geologic hazards in the Mount Washington quadrangle include earthquakes, flooding along entrenched drainages, and landsliding or slumping on steep mountain slopes underlain by shales (eg. upper Sandia Formation). Quaternary normal faults along the Rio Grande Rift represent a potential regional earthquake risk. All high-angle faults and range boundary faults mapped in the Mount Washington quadrangle should be considered capable of normal slip in the regional extensional stress domain of the rift. However, there is no indication of Holocene or Pleistocene displacement of any fault within the quadrangle. Mapped faults in adjacent quadrangles do show signs of Quaternary movement, so the threat of regional shaking due to earthquakes cannot be ignored.

An inactive landslide deposit (mapped as Qca) lies upslope from the HERTF site, on the east wall of the canyon. Madera limestone blocks have locally slid down this slope where riding on northeast dipping shales of the Sandia Formation. The landslide deposit appears to be buttressed by crystalline bedrock at its western terminus. It is unlikely to be a future hazard to the HERTF site, but its existence should be noted. Extended periods of high precipitation could reactivate portions of this landslide, or form a debris flow from the loose blocks.

All areas underlain by recent alluvial deposits (QHva and Qvy3) represent localities of potential flash flooding.

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REFERENCES

Bates, R. L., and Jackson, J. A., eds., 1987, Glossary of geology: Alexandria, Virginia, American Geological Institute, 788 p.

Bauer, P. W., Karlstrom, K. E., Bowing, S. A., Smith, A., and Goodwin, L. B., 1993, Proterozoic plutonism and regional deformation—new constraints from the southern Manzano Mountains, central New Mexico: New Mexico Geology, v. 15, no. 3, p. 49–55.

Cavin, W. J., 1985, Precambrian geology of the Manzanita Mountains, Bernalillo County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 144 p.

Gile, L. H., and Hawley, J. W., 1966, Periodic sedimentation and soil formation on an alluvial-fan piedmont in southern New Mexico: Soil Science Society of America Proceedings, v. 30, p. 261–268.

Gile, L. H., Hawley, J. W., and Grossman, R. B., 1981, Soils and geomorphology in the Basin and Range area of southern New Mexico-Guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources Memoir 39, 222p.

Karlstrom, K. (compiler), et al., 1994, Geology of the Tijeras 7.5-minute quadrangle, Bernalillo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-File Report 396.

Karlstrom, K. E., Dallmeyer, R. D., and Grambling, J. A., 1997, ^{40}Ar/^{39}Ar evidence for 1.4 Ga regional metamorphism in New Mexico: Implications for thermal evolution of lithosphere in the southwestern USA: Journal of Geology, v. 105, p. 205–223.

Kelley, V. C., 1977, Geology of the Albuquerque basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 33, 60p.

Kluth, C. F. and Coney, P. J., 1981, Plate tectonic of the ancestral Rocky Mountains: Geology, v. 9, p. 10–15.

Kirby, E., Karlstrom, K. E., and Andrinicos, C. L., 1995, Structural and thermal setting during emplacement of the Sandia pluton: New Mexico Geological Society Guidebook 46, p. 219-225.

Love, D. L. (compiler), et al., 1996, Geology of the Hubbell Springs 7.5-minute quadrangle, Bernalillo and Valencia Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-File Report 426.

Myers, D. A., and McKay, E. J., 1970, Geologic map of the Mount Washington Quadrangle, Bernalillo and Valencia Counties, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ 886.

Myers, D. A., and McKay, E. J., 1976, Geologic map of the north end of the Manzano Mountains, Bernalillo and Valencia Counties, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-968.

Parchman, M. A., 1981, Precambrian geology of the Hell Canyon area, Manzano Mountains, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 108 p.

Reiche, P., 1949, Geology of the Manzanita and north Manzano Mountains, New Mexico: Geological Society of America Bulletin, v. 60, no.7, p. 1183–1212.

Royden, L. H., 1996, Late Paleozoic deformation of the Ancestral Rocky Mountains: result of an Andean margin along southwestern North America ? (abs.): Geological Society of America Abstracts with Programs, v. 28, no. 7, p. A-270.

Thomas, E., Van Hart, D., McKitrick, S., Gillentine, J., Hitchcock, C., Kelson, K., Noler, J., and Sawyer, T., 1995, Conceptual geologic model of the Sandia National Laboratories and Kirtland Airforce Base: Technical Report, Site-Wide Hydrogeologic Characterization Project Organization 7584, Environmental Restoration Program. Prepared by GRAM, Incorporated, Albuquerque, New Mexico; and William Lettis and Associates, Oakland, California, various pagination.

Table 1. Summary and interpretation of driller's logs for water-supply wells on Isleta Reservation and lithologic and geophysical logs on Sandia National Laboratories site and Kirtland Airforce Base (Plate I).

Well No.: **RWP-14**
Date drilled: 1958
Drilling method: unknown
Location: SE1/4, SW1/4, SW1/4, Section 12, T08N, R04E, NMPM
Elevation: 5810±20 feet (estimate from topographic map)

Depth (feet)	**Driller's Log**	**Interpretation**	**Notes**
0-3	top soil	piedmont alluvium	
3-40	caliche and boulders	(calcic soil?)	
40-85	gray limestone, broken	Yeso	
85-100	gray limestone, broken	Formation (?)	
100-140	red clay, sandy		
140-155	yellow clay		
155-235	red clay	Abo	
235-370	red clay	Formation	
370-395	red sand		water
395-405	red sand		
405-415	red clay		

Well No.: **RWP-24**
Date drilled: 1967 and 1968
Drilling method: unknown
Location: SE1/4, SE1/4, NW1/4, Section 26, T08N, R04E, NMPM
Elevation: 5730±20 feet (estimate from topographic map)

Depth (feet)	**Driller's Log**	**Interpretation**	**Notes**
0-3	top soil	piedmont alluvium	
3-6	white shale	(calcic soil)	
6-65	gravel and boulders	Santa Fe Group	
65-105	red shale	Abo Fm.	one-day drilling
105-125	red shale and boulders		one-day drilling
125-145	red rock, hard		one-day drilling
145-155	boulders		one-day drilling; water
155-160	red shale		water at 160 ft (1967): water at 130 ft (1968)
160-170	red shale		
170-205	red shale		
205-270	red shale		
270-290	brown sand		
290-297	shale		stop date: 07-09-68 depth to water: 162 ft

Table 1 (continued).

Well No.: **RWP-29**
Date drilled: 1970 and 1976
Drilling method: unknown
Location: SE1/4, SE1/4, SE1/4, Section 18, T08N, R05E, NMPM
Elevation: 6010±20 feet (estimate from topographic map)

Depth (feet)	Driller's Log	Interpretation	Notes
0-4	top soil and gravel	piedmont alluvium and Santa Fe Group	starting date: 10-7-70
4-10	gravel		
10-40	gravel		one-day drilling
40-65	gravel and boulders		one-day drilling
65-70	gravel and boulders		
70-78	limestone	Madera Formation	
78-91	limestone		
91-105	shale and boulders		date: 10-19-70
105-125	limestone		
125-155	brown shale		
155-163	gray shale		
163-170	limestone		date: 10-23-70
170-175	limestone		
175-178	broken limestone		water
178-188	limestone		stop date: 10-30-70 depth to water: 160 ft flow rate: 20 gpm
189-216	broken limestone		extended hole: 1976
216-222	gray shale		depth to water: 188 ft flow rate: 12 gpm

Well No.: **MW-13**
Date drilled: unknown
Drilling method: unknown
Location: NE1/4, Section 3, T09N, R04E, NMPM
Elevation: 5660±20 feet (estimate from topographic map)

Depth (feet)	Lithologic Summary	Interpretation
0-130	gravel and sand	undivided piedmont alluvium and Santa Fe Group

Table 1 (continued).

Well No.: **KAFB-1901**
Date drilled: unknown
Drilling method: unknown
Location: SE1/4, SW1/4, NE1/4, Section 35, T09N, R04E, NMPM
Elevation: 5750±20 feet (estimate from topographic map)

Depth (feet)	**Lithologic Summary**	**Interpretation**
0-150	gravel and clay	undivided piedmont alluvium and Santa Fe Group
150-240	red-brown to light-brown and gray clay, sandstone and limestone	Yeso Formation(?)

Well No.: **TRN-1**
Date drilled: unknown
Drilling method: unknown
Location: SE1/4, NE1/4, SW1/4, Section 35, T09N, R04E, NMPM
Elevation: 5730±20 feet (estimate from topographic map)

Depth (feet)	**Lithologic Summary**	**Interpretation**
0-160	gravel, sand, minor silt	undivided piedmont alluvium and Santa Fe Group
160-515	red-brown grayish-red, micaceous claystone, siltstone and sandstone	Abo Formation or undivided Triassic

Well No.: **TRS-1**
Date drilled: unknown
Drilling method: unknown
Location: NW1/4, SE1/4, SE1/4, Section 35, T09N, R04E, NMPM
Elevation: 5780±20 feet (estimate from topographic map)

Depth (feet)	**Lithologic Summary**	**Interpretation**
0-135	sand and gravel	undivided piedmont alluvium and Santa Fe Group
135-480	olive-gray to dark-brown limestone, siltstone and shale	Madera Formation

Table 1 (continued).

Well No.: **95-BH2**
Date drilled: August 1995
Drilling method: Hollow-stem auger
Location: NW1/4, NW1/4, NE1/4, Section 24, T09N, R04E, NMPM
Elevation: 5852 feet

Depth (feet)	**Lithologic Summary**	**Interpretation**
0-18	silty sand and clayey sand	cienega deposits, water at 15 ft.
18-60	gravel, clayey gravel and silty clay	valley-fill alluvium

Well No.: **95-BH4**
Date drilled: August 1995
Drilling method: Hollow-stem auger
Location: NW1/4, SW1/4, NW1/4, Section 24, T09N, R04E, NMPM
Elevation: 5790 feet

Depth (feet)	**Lithologic Summary**	**Interpretation**
0-36	sandy gravel, silty sand and gravelly sand	valley-fill and piedmont alluvium

Well No.: **95-BH7**
Date drilled: August 1995
Drilling method: Hollow-stem auger
Location: SE1/4, NW1/4, SE1/4, Section 24, T09N, R04E, NMPM
Elevation: 5730 feet

Depth (feet)	**Lithologic Summary**	**Interpretation**
0-31	sandy and clayey gravel and sand	valley-fill alluvium water at 28 ft.
31-43	sand	valley-fill alluvium
43-61	sandstone	Sandia Formation

Table 2. Table showing tentative correlations of alluvial units in the study area, based on stratigraphic relations, landscape-topographic position, degree of soil development and physical correlation of units.

This Study	Hubbell Springs Quadrangle *Love and others (1996)*	Sandia National Laboratories *Thomas & others (1995)*
QHva, QHvaf	QHsc, QHfp, QHae	H9, H8
Qvy3	QHt20, QHt19	H7
Qvy2, Qpy2	Qt17-Qt19	P6
Qvy1, Qpy1		P5
Qvm3, Qpm3	Qt7-Qt18	---
Qvm2, Qpm2		
Qvm1, Qpm1		
Qvo2, Qpo2	QT3-Qt6	
Qvo1, Qpo1		P4, P3
QTpo, QTspc3	Tf2	P3, P2, P1, Santa Fe Group
QTspc1, QTspc2	Tf1	Santa Fe Group

Table 3. Description of Map units, Mount Washington 7.5' quadrangle.

CENOZOIC DEPOSITS

Valley-Fill Alluvium

QHva
QHvaf Stream alluvium, undivided (upper Holocene to historic)—Poorly consolidated pebble- to cobble conglomerate and fine-to coarse-grained sand with minor accumulations of boulders and silt-to clay-rich beds. Unit forms very narrow to broad streams with elongate cobble and boulder bars and floodplains that are inset against Qvy. Bar and swale topography is well developed. Soils are very weakly developed and possess disseminated to no pedogenic carbonate. Unit QHvaf is differentiated on the basis of fan-surface form where is occurs along the valley margins of Coyote Canyon. Unit is correlative to H8 and H9 of Thomas et al. (1995) and QHsc and QHfp of Love et al. (1996) (Table 2).

Qvy Stream alluvium, undivided (upper Pleistocene to Holocene) — Poorly consolidated light-brown and light reddish-brown to gray-brown pebble and cobble conglomerate and sand with minor accumulations of boulders and silt-to clay-rich beds. Clasts are subangular to subrounded and typically unweathered and are not pitted; however clasts are locally weathered in Cañada Colorada. Soil development is quite variable and ranges from weakly developed stage I to deposits possessing multiple calcic horizons with stage II and III calcium-carbonate morphology. The unit forms broad valley-floor deposits and terraces inset against unit Qpo on SNL-KAFB. Bar and swale topography is locally well developed. Unit is differentiated into three subunits that sit 1.4 and 2.9 m above local grade. Unit **Qvy(t)** contains interbedded calcareous spring deposits at Coyote Springs. Unit is correlative to P5, P6 and H7 of Thomas et al. (1995) and QHt20 through QHt18 of Love et al. (1996).

Qvy3 Stream alluvium (uppermost Pleistocene to Holocene) — Stream terraces, adjacent to historic channels, that are underlain by very weakly developed soils. Unit locally forms two terraces along major drainages.

Qvy2 Stream alluvium (upper Pleistocene) — Valley-fill and fan-deposits bordering valleys of Cañada Colorada, Hell's Canyon Wash and Cañon de Sanchez). Bar and swale topography is subdued and locally buried by light-brown to light reddish-brown silty sand. Soils possess weak to moderately strong pedogenic development with stage I to locally stage III carbonate morphology. Soil development is highly variable and unit locally exhibits orangish-brown mottles and white carbonate-rich clay (marl?), indicating fluctuating groundwater conditions prior to abandonment of the unit.

Qvy1 Stream alluvium (upper Pleistocene) — Stream terraces and elongate valley-border fans inset against Qpo on SNL-KAFB. Unit is correlative to P5 (Table 2), which has radiocarbon date of about 21,000 years BP (Thomas et al., 1995).

Qvm Stream alluvium, undivided (middle Pleistocene) — Moderately consolidated pebble and cobble conglomerate and sand. Soil development is variable typically possesses multiple (cumulic) buried soils with Bk horizons that exhibit stage II and III calcium-carbonate morphology. The unit forms slightly to moderately dissected valley-floor deposits and terraces inset against unit Qpo. Unit is locally mantled by Qvy in narrow to broad swales. Unit is differentiated into two subunits that sit 3.5 and 8.5 m above local grade.

Qvm3 Stream alluvium (upper-middle Pleistocene) — Forms broad, low-relief elongate fans associated with Seis Canyon and several small drainage basins south of Hell's Canyon. Surface is weakly dissected and locally reddish-brown in color. Unit buried and is inset against Qvm1.

Qvm2 Stream alluvium (middle Pleistocene) — Forms terraces and elongate valley-border fans about 3.5 to 4 m above local base level.

Qvm1 Stream alluvium (middle Pleistocene) — Forms terraces and elongate valley-border fans about 7 to 8.5 m above local base level.

Qvo Stream alluvium, undivided (middle to lower Pleistocene) — Moderately consolidated gravel and sand inset that forms moderately dissected and elongated terraces along the margins of QTspc. Deposits are poorly exposed and locally possess multiple buried soils with stage III (IV in gravelly substrate) carbonate morphology. Unit is buried and inset by Qvm and Qvy deposits.

Qva Stream alluvium, undivided (middle to lower Pleistocene) — Undivided deposits of Qvo and Qvm. Unit is inset by Qvy along western margin of study area, and is locally buried by Qvy along the mountain front.

Piedmont-slope alluvium

Qpy Piedmont alluvium, undivided (upper Pleistocene) — Unconsolidated gravel and sand associated with broad, slightly dissected mountain-front fans in SNL-KAFB. Qpy is inset by historic and Holocene stream channels and terraces. Unit is divided into two subunits on the basis of inset relations and soil development.

Qpy2 Piedmont alluvium (upper Pleistocene) — Forms broad range-front fan deposits that exhibit stage I and II carbonate morphology. Unit is correlative to P6 of Thomas et al. (1995).

Qpy1 Piedmont alluvium (upper Pleistocene) — Forms broad fan deposits inset against Qpo. Soils exhibit strong stage II carbonate morphology. Unit is correlative to P6 (Table 2). A radiocarbon date of about 21,000 years BP is reported in this unit (Thomas et al., 1995).

Qpo Piedmont alluvium, undivided (lower to middle Pleistocene) — Poorly to moderately consolidated and calcium-carbonate cemented sand and subrounded to subangular cobble to pebble conglomerate inset against unit QTspc. Unit grades to the west where it is truncated by the Hubbell Springs fault zone (Love et al., 1996). The deposit surface is moderately dissected, with rounded hill slopes, and sits about 5 to 10-m above local base level. Unit is locally differentiated into four subunits on the basis of inset relationships. Soils are partially stripped, but locally exhibit stage III carbonate morphology. Unit is tentatively correlated to P4 (Table 2). A radiocarbon date of about 51,000 years BP was reported in unit P4 (Thomas et al., 1995).

Qpo2 Piedmont alluvium (middle Pleistocene) — Unit is inset against QTpo and QTspc.

Qpo1 Piedmont alluvium (middle Pleistocene) — Unit is inset against Qpo2 and is locally subdivided into **Qpo1a** (older) and **Qpo1b** (younger) units on the basis of inset relations.

QTpo Pediment alluvium (Upper Pliocene(?) to lower Pleistocene) — Well consolidated and calcium-carbonate cemented sand and conglomerate inset against unit QTspc. The unit is poorly exposed and grades to the west where it is truncated by the Hubbell Springs fault zone. The deposit surface is moderately and locally exposes partially stripped soils with stage IV to V carbonate morphology.

QTspc Santa Fe Group, piedmont alluvium (lower Pleistocene(?) to Pliocene) — Well consolidated and calcium-carbonate cemented conglomerate and sandstone exposed on the footwall of the Hubbell Springs fault. Conglomerate is clast supported and contains Paleozoic limestone, schist, greenstone and quartzite with minor reddish-brown (Abo or Yeso Fm?) sandstone. Limestone clasts are locally deeply pitted. The deposit is 8- to 20-m thick and unconformably overlies lower Mesozoic and upper Paleozoic rocks (Table 1; Love et al., 1996; Thomas et al., 1995). Exposures are generally poor in the study area, except along deeply dissected reaches of Cañada Colorada. Unit is locally differentiated in **QTspc1** (older), **QTspc2** and **QTspc3** (younger) on the basis of inset relations. The deposit surface is moderately to deeply dissected. Soils are strongly developed, partially stripped and exhibit stage IV and V carbonate morphology. Unit is correlative to Tf1 and Tf2 of Love et al. (1996) and forms the highest geomorphic surface on the piedmont study area.

Colluvium, Spring Deposits and Artificial Fill

af Artificial fill (historic) — Dumped fill and areas effected by human disturbances. Mapped where deposits are areally extensive.

Qca Colluvium and alluvium, undivided (Holocene to upper Pleistocene) — Poorly consolidated, poorly sorted and stratified, fine- to coarse-grained, clast- and matrix-supported deposits derived from a variety of mass-movement hill-slope processes, including debris flow, shallow slump and creep. Deposits are delineated by sedimentary character and surface morphology. Clasts are typically angular and composition generally reflects local provenance. Colluvium is common on hillslopes, but is differentiated where areally extensive. May include landslide deposits on steeper slopes.

Qtr Spring deposits (middle to upper(?) Pleistocene) — Light- dark-gray massive limestone interlayered with quartzite breccia near Coyote Springs (N1/2, Section 24, T09N, R04E, NMPM).

TERTIARY INTRUSIVE ROCKS

Mafic dike (Tmi)

Dark green to black dikes intruded along some north-trending faults or fissures. Dikes are chloritically altered and composed mostly of calcic plagioclase and pyroxene (Parchman, 1980). These undated basaltic dikes may be associated with early extension along the Rio Grande rift in middle Cenozoic time.

PALEOZOIC ROCKS

Py Yeso Formation, undivided (Lower Permian)—Yellowish brown, orangish brown, and reddish brown sandstone and shale with interbedded gray limestones; recognized in subsurface only (Table 1).

Pa Abo Formation (Lower Permian)—Reddish brown to light gray sandstone, conglomeratic sandstone and siltstone interbedded with red mudstones; recognized in subsurface only (Table 1).

Pm Madera Group, undivided (Pennsylvanian to Lower Permian?) (**Pmu** + **Pml**).

Pmu Madera Group, upper arkosic unit (Pennsylvanian to Lower Permian?)—Interbedded arkosic conglomeratic sandstone, sandstone, siltstone, mudstone and limestone; mostly slope to ledge forming. Yellowish to reddish brown and light gray arkosic to feldspathic sandstones and conglomeratic sandstones are lenticular and grade into pale yellow brown, gray and purplish gray mudstones and micaceous siltstones. Clastic units locally contain silicified wood. Tabular, ledge-forming, light to dark gray, fossiliferous, limestones are commonly interbedded with mudstones and may locally contain feldspathic detritus. Red muddy soils are common on the upper arkosic member. Generally equivalent to Pine Shadow and La Casa Members of Wild Cow Formation of Myers (1973) or Pmuc and Pmud of Myers and McKay (1970). As much as 400 ft (120 m) thick, with erosional top.

Pml Madera Group, lower cherty fossiliferous limestone unit (Pennsylvanian)—Mostly cliff-forming, gray fossiliferous limestone with minor interbedded shales and quartzose to feldspathic sandstones and conglomeratic sandstones. Individual massive to nodular limestone beds are commonly 20–30 feet (3–9 m) thick and may be as much as 60 feet (18 m) thick. Irregular masses of black to reddish orange chert are common in massive limestone beds. Nodular limestones often weather to mottled gray and brown surfaces. Limestones are interbedded with light to dark gray and yellowish brown shales, nodular shales and yellowish brown to greenish gray siltstones that are often micaceous. Siltstones locally grade upward into lenticular to tabular quartz arenites and quartz pebble conglomerates of light gray to yellowish brown color. Clastic units locally contain silicified wood. Includes Los Moyos Limestone and overlying Sol se Mete Member of Wild Cow Formation of Myers (1973), or Pml and Pmub of Myers and McKay (1970). These mostly cliff forming units are often separated by a gentle slope break (or breaks), but otherwise appear to be lithologically similar. Additional study of the Wild Cow/Los Moyos contact and its lithologic mapability seems warranted. Approximate thickness 500 to 800 feet (150–240 m).

Ps Sandia Formation (Middle Pennsylvanian)—Mostly slope-forming shales and siltstones grading down into basal quartz pebble conglomerates and up into thin bedded limestones. Limestones and shales occur in uppermost 20 ft (7 m) near gradational contact into overlying cliff-forming limestones of Madera Formation. Well indurated (siliceous) basal quartz pebble conglomerates are thickest (20–40 ft; 6–12 m) in northwestern third of quadrangle and generally thin to low ledge-forming conglomerates (1–2 m thick) and sandstones in southeast quadrant. Sparse metamorphic and limestone pebbles or shell fragments are locally present in thinner (lower energy?) basal zones (e.g. NE¼ sec. 7, T8N, R5E). Light gray to yellowish brown conglomerates of basal zone grade upward into yellowish brown, gray and greenish gray sandstones and micaceous siltstones interbedded with yellowish brown, gray and black shales or carbonaceous shales. Medial shaley zone is 100–150 ft (30–45 m) thick and commonly mantled with blocky limestone colluvium (generally not mapped) derived from overlying Madera Formation. Where locally well exposed along road to Sol se Mete Peak, medial shales also contain a thin red siltstone that may represent an ancient subaerial weathering zone. Conglomeratic sandstones are unusually abundant in medial to upper Sandia about ½ mi north of HERTF site and one mile south of USGS Seismic Laboratory (NE¼, Sec. 30, T9N, R5E; and SE¼ Sec. 7, T8N, R5E). Average thickness is 200 ft (60 m); ranges from about 80–300 ft

(24–90 m).

PROTEROZOIC ROCK UNITS

Ygd Granitic to rhyolitic dike—light gray granite porphyry dike about 6 m thick with flow-banded rhyolitic margins about 0.6 m thick. Appears to parallel regional foliations of adjacent metasedimentary rocks; pinches out to NE along strike. Contains medium to coarse phenocrysts of quartz, K-feldspar, albite and minor muscovite plus biotite in a chalky (partly kaolinized?) groundmass of similar mineralogy. Muscovite yields $^{40}Ar/^{39}Ar$ plateau age of 1428 ± 3.6 Ma (M. Heizler, New Mexico Geochronology Research Lab, written commun. 1997), which is interpreted as the cooling age of the dike. Dike post-dates regional metamorphism and associated ductile deformation.

Quartz veins (Xqv)

Veins and veinlets of massive, milky-white quartz generally parallel to the regional fabric although smaller veinlets (2-5 cm) locally cross cut the fabric. In some locations, thin quartz veinlets are folded with the main fabric as axial plane. Mappable quartz veins consist of white quartz with minor hematite and brown calcite.

Manzanita Granite (Xmg)

The Manzanita granite is a homogenous quartz monzonite with 1-4 cm K-feldspar euhedral phenocrysts. In zones of stronger deformation K-feldspar porphyroclasts have an oval shape and show dynamic recrystallization and grain size reduction along margins. Foliation and lineation are variably developed in the granite with zones of well-develop L-S fabrics that grade into undeformed granite. Other zones contain a strong linear element and lack any planar tectonic fabric. Manzanita granite shows a gradational contact along the northern boundary into a strongly deformed, reddish-orange, fine grained foliated felsic rock that Cavin (1985) named metarhyolite but which is interpreted here as mylonitic Manzanita granite. Foliation is defined by elongate quartz grains, ovoid shaped K-feldspar and aligned muscovite grains and is parallel to lithologic contacts. Mineral lineations are defined by elongate quartz grains and aligned muscovite and is commonly down dip. Asymmetric K-feldspar porphyroclasts and shear bands within the deformed granite record north-directed thrusting. U-Pb dating of zircons indicates an age of 1632 ± 45 Ma for this unit (Unrue, unpublished data).

Leucocratic granite, aplite and pegmatite (Xlg)

Leucocratic granite, aplite and pegmatite dikes occur as irregular pods within the Manzanita granite and greenstone unit. Both pods and dikes are frequently parallel to local tectonic fabrics. Aplite occurs as white to reddish-white fine grained rock with mm-size phenocrysts of quartz and K-feldspar in a fine-grained matrix. Certain bodies of aplite have a strong lineation and no foliation. Pegmatite has similar outcrop pattern as aplite but occurs more generally in m-size dikes and sills. Pegmatite consists of cm-size K-feldspar phenocrysts and irregular stringers of quartz and minor plagioclase feldspar. Probably represents evolved units of Manzanita granite.

Biotite granite (Xbg)

Biotite granite occurs as dikes and irregular shaped intrusions. This unit is light pink to pinkish gray with granitic textures and minor development of a tectonic fabric. Foliation in these rocks is defined by a weak alignment of chlorite and elongate quartz grains. Includes quartz monzonite of Parchman (1980) and large outcrops at NW corner of quadrangle.

Diorite (Xd)

This unit consists of diabase, diorite and quartz diorite that occur within the greenstone and metatuff units and are grouped together based on lithologic similarity and field occurrence. These three rock units occur as small, poorly-exposed intrusive bodies some of which have a sill-like outcrop pattern. Where observed in outcrop these lithologies have a blocky, massive appearance with a brown to red-brown weathered surfaces. Fresh samples show an aphanitic texture with rare plagioclase feldspar laths that are occasionally aligned perhaps defining an original flow texture. Local schistosity is developed in some exposures and is parallel to regional structures.

Mafic intrusives (Xmi)

This unit consists of amphibolite, chlorite-schists and gabbroic intrusive rocks. These rocks occur as m-thick, discontinuous sills and parallel to the regional fabric although several exposures have apophyses that cross-cut foliation. Individual sills show transition from undeformed mafic rock in the sill interior to chlorite schist along sill margins. Parchman (1980) reports that mafic intrusives range from chlorite schists to amphibolites towards the

Manzanita granite. Mafic intrusive parent rocks include basalt and gabbroic sills.

Schist and Phyllite (Xs)

Mottled quartz-rich schist and phyllite with red, hematitic and green fuchsite-rich (?) zones that occurs as discontinuous layers of variable thickness. Schistosity is complexly injected with lense-shaped quartz pods. Phyllite occurs also in a band of green to reddish green phyllite up to 60 m thick between two exposures of deformed Manzanita granite. Contacts with the deformed Manzanita granite at north end of quadrangle are strongly tectonized with interlayering of deformed granite and green phyllite. Parent rocks for the schist probably consisted of impure quartz-rich siltstones. This unit includes Coyote Schist and Coyote Phyllite of Cavin (1985).

Quartzite (Xq)

Massive to thickly-bedded, gray- to milky white quartzite. Original bedding in the quartzite consists of 1-5 mm-thick black and red hematite-rich layers. Cross bedding is locally preserved. Interlayered with the quartzite are greenish-gray micaceous quartzite that contain up to 35% muscovite and chlorite. Protolith for the thickly bedded quartzite was pure quartzose sands intermixed with impure sandstones and siltstones. Includes the Cerro Pelon and Coyote quartzites of Cavin (1985).

Lithic arenite (Xla)

This rock unit consists of a variety of metasedimentary rocks including metawacke, metaarkose and impure metaquartzite. Up to 50% of this unit is a brown weathered impure arkosic metaquartzite with light green to gray fresh surfaces. Schistosity is variably developed throughout most of the unit and appears to be better developed towards the contact with the Manzanita granite. Compositional layering (S0) is variably preserved and is generally at low angles to the dominant schistosity (S1). Metamorphic grade and field appearance of this unit varies towards the Manzanita granite suggesting development of a contact aureole associated with granite emplacement. Away from the Mazanita granite metasedimentary rocks have a granular appearance with a weak foliation. Samples of metasediments near the Manzanita granite are granoblastic hornfels with porphyroblasts of andalusite, sillimanite, possible kyanite and garnet. Schists and slates are also more evident closer to the Manzanita granite contact.

Phyllite and schist (Xp)

This rock unit is interlayered and gradational with the lithic arenite but has been mapped as a separate unit in several zones where it constitutes greater than 90% of the exposure. This unit also occurs throughout the metasedimentary unit (Xms) as <5 m thick beds that were too small to map as individual units. This unit consists of blue to light grayish green phyllite that become more schistose and massive (high grade) in exposures closer to the Manzanita granite. Parent rocks for this lithology were siltstones.

Metachert and Jasperoid (Xc)

Metachert occurs as prominent, low-lying outcrops infolded and interlayered with the metasedimentary and blue phyllite unit. These layers range from several cm to m thickness and are discontinuous along strike frequently pinching off within phyllitic layers or adjacent to chlorite-rich amphibolites. This unit varies from white to hematite-stained quartz-rich sediment with narrow miceous zones parallel to local foliation. Jasperoids consist of red-stained, discontinuous pods of jasper. This unit marks the transition from volcanic to clastic deposition.

Dacite tuff (Xdt)

The metatuff unit is gray to light grayish green dacite with a well-developed schistosity. Major parts of this unit contains flattened ovoid shaped fragments of light gray to buff phyllite, chlorite phyllite, metaquartzite and greenstone. These fragments range in size from 4 to 30 cm and are aligned parallel with the schistosity. Towards the gradational contact with the metasedimentary unit the metatuff contains abundant (up to 80%) blue to blue-gray phyllite fragments. The matrix of the metatuff is fine grained, gray to greenish gray. The metatuff is interpreted to be the metamorphic equivalent of a crystal and vitric-crystal tuff that is dominantly dacite with minor andesite. Includes the Lacorocah metatuff of Parchman (1980).

Intermediate metavolcanics rocks (Xiv)

Buff, schistose bands intimately interfingered with the greenstone (Xmv) and metatuff (Xmt) units. This unit also defines broad, regional folds. Lithologies within this unit consists of a mixture of volcaniclastic rocks including quartz-mica phyllites and volcanic rocks with an andesitic composition (Parchman, 1980). In outcrop this unit has a brown to gray-green color with a moderately well-developed schistosity.

Mafic metavolcanic rocks (Xmv)

Heterogeneous metavolcanic unit composed of basaltic greenstones, intermediate volcanics, volcaniclastic greenschists (quartz-actinolite-chlorite schists) and metapelites. Rare epidote-rich bands are present in some areas and may denote margins of metamorphosed pillows. Other primary features include compositional layering defined by white, plagioclase(?)-rich layers that are parallel to foliation and plagioclase-phenocrystic volcanic rocks. Unit grades upwards to volcaniclastic rocks (Xdt) and is interlayereπd with mappable units of felsic to intermediate volcanic rocks (Xiv and Xdt). Unit includes Coyote greenstone and Isleta greenstone of Cavin (1985) and the lower part of Tijeras greenstone of Connolly (1981).

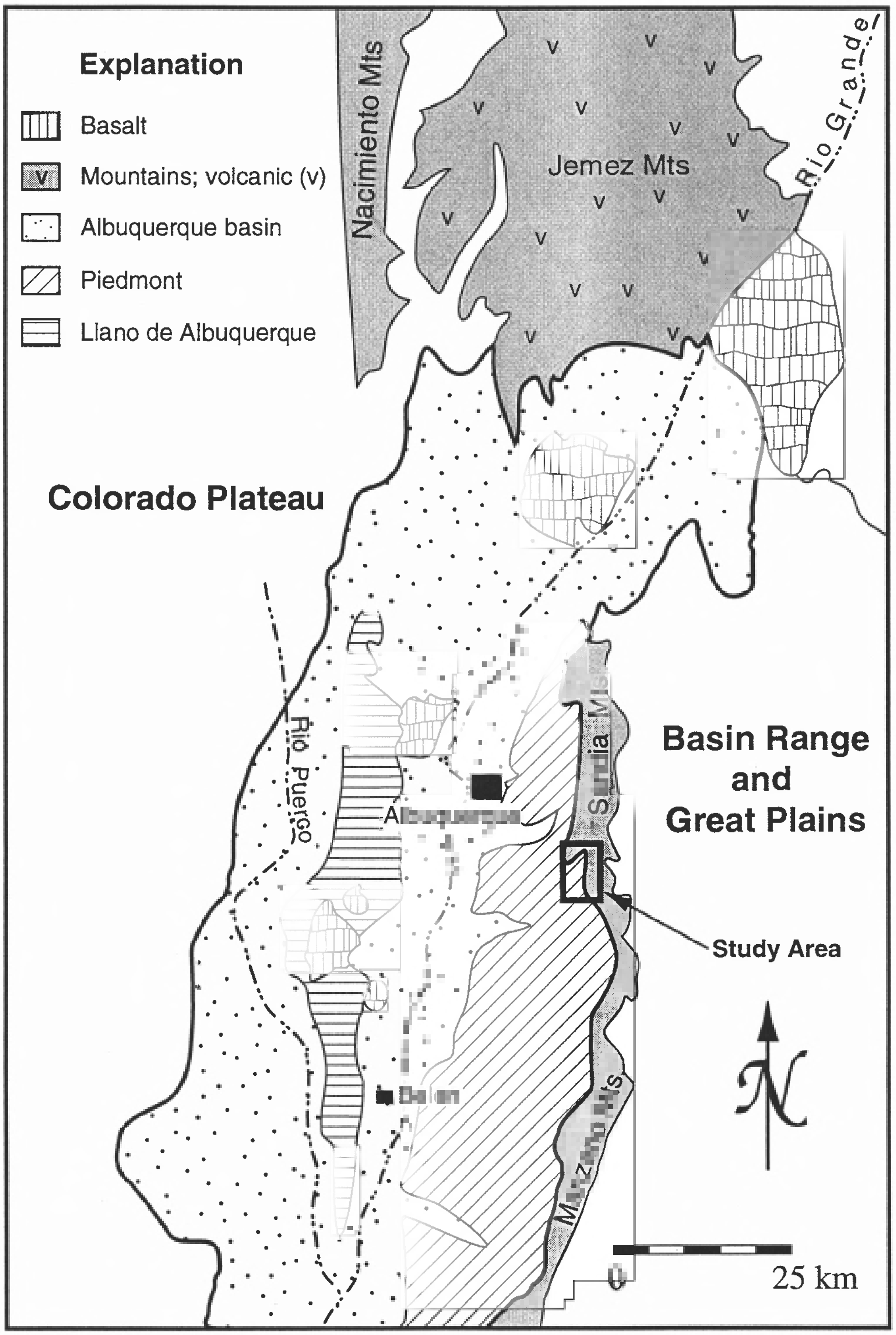


Figure 1. Albuquerque basin and study area location, including major landforms, geologic units and geomorphic provinces.

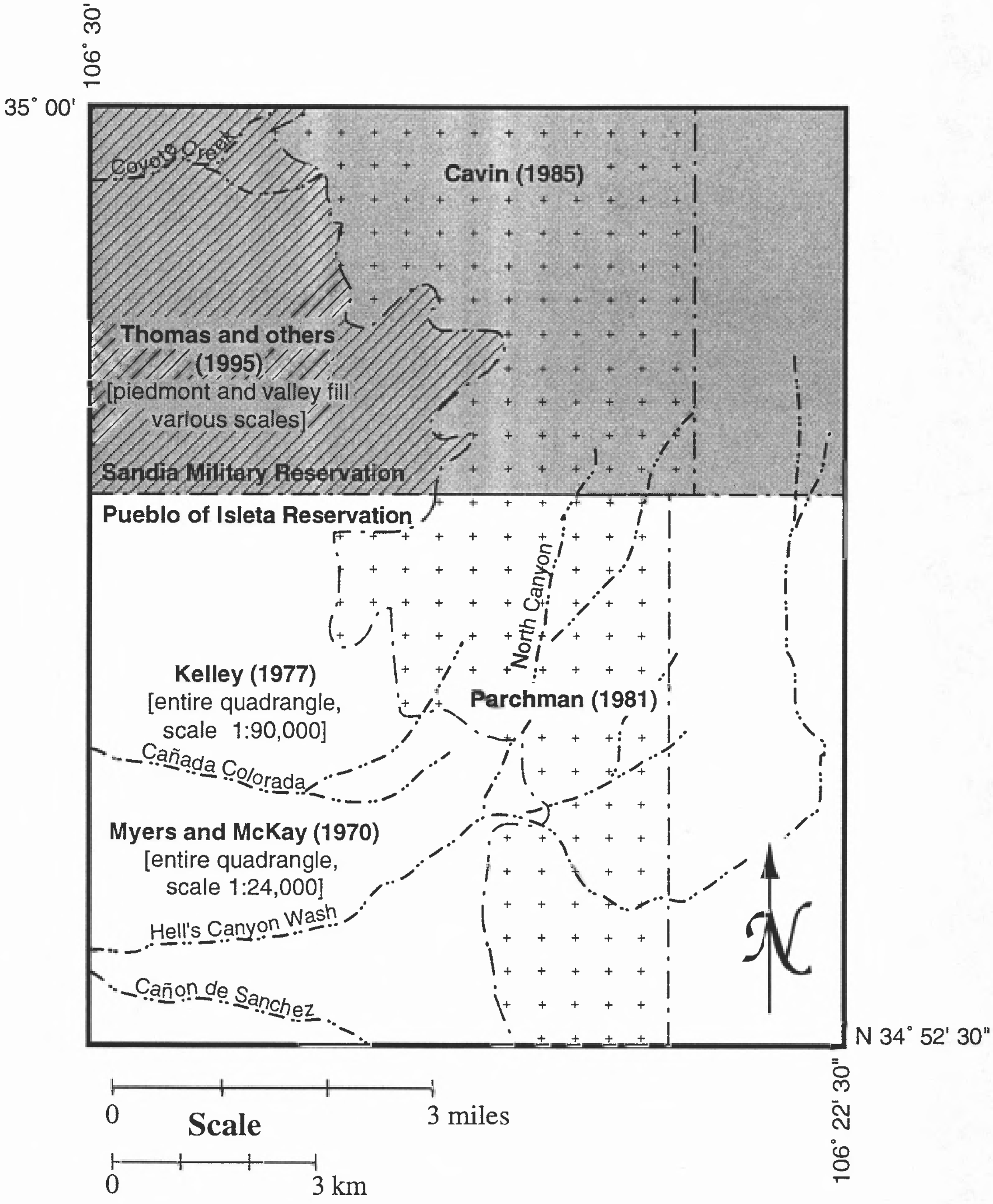


Figure 2. Index to previous geologic mapping within the Mount Washington quadrangle.

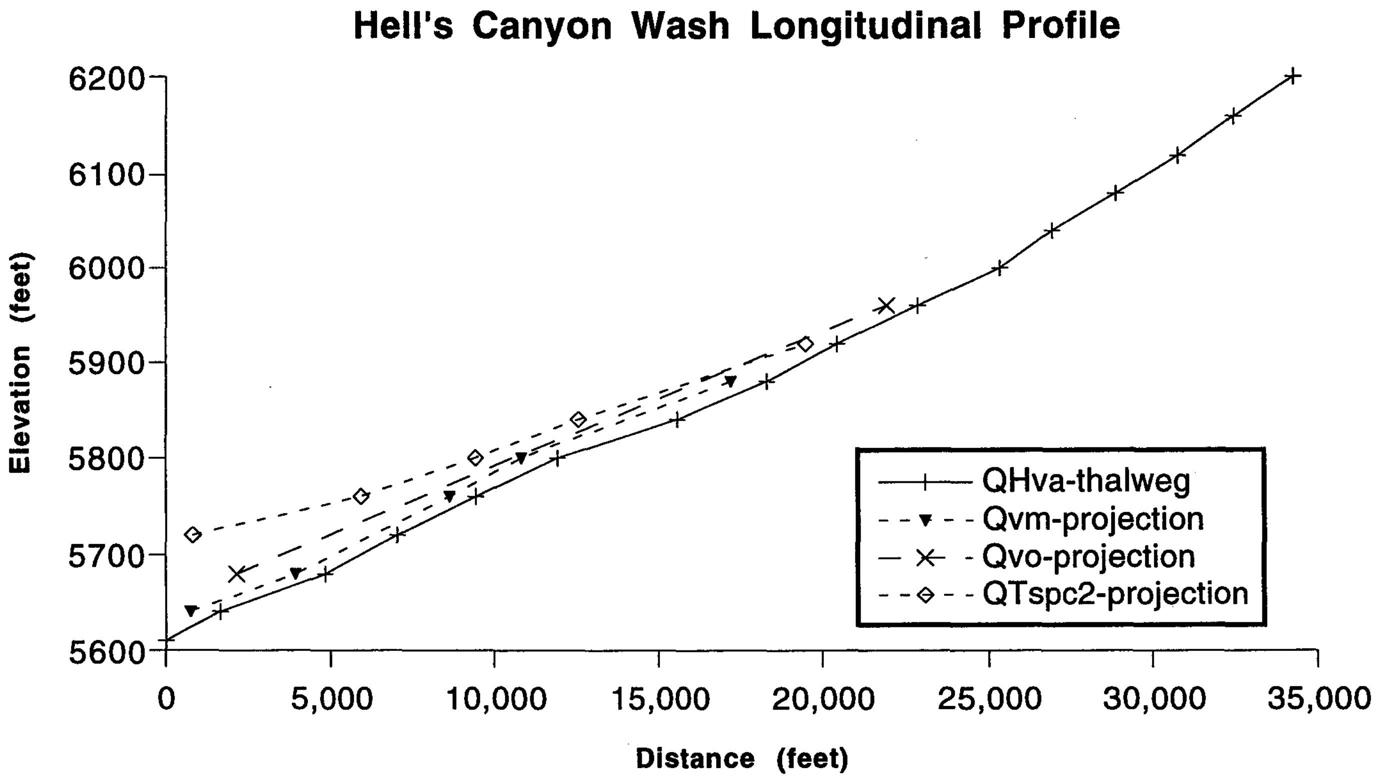
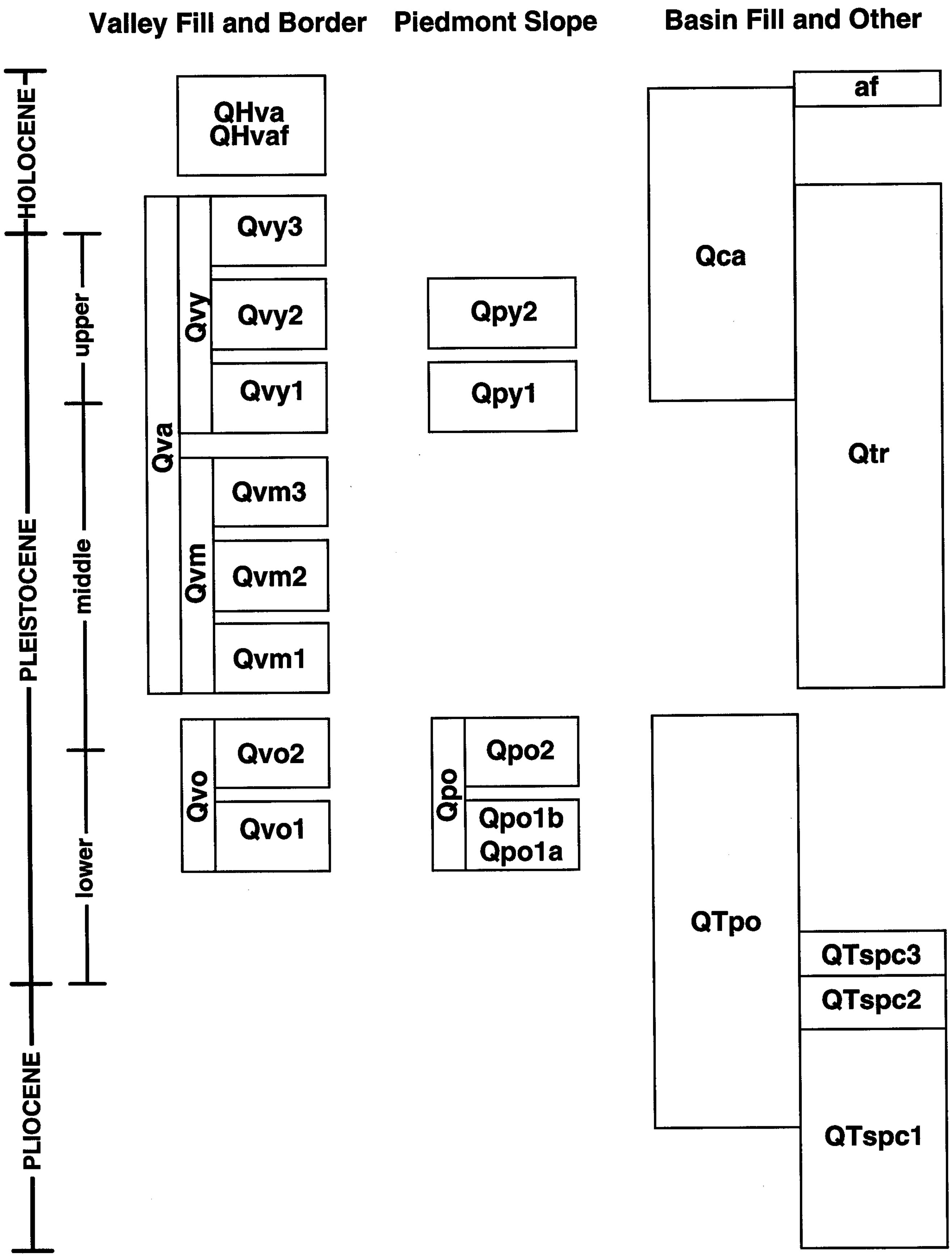


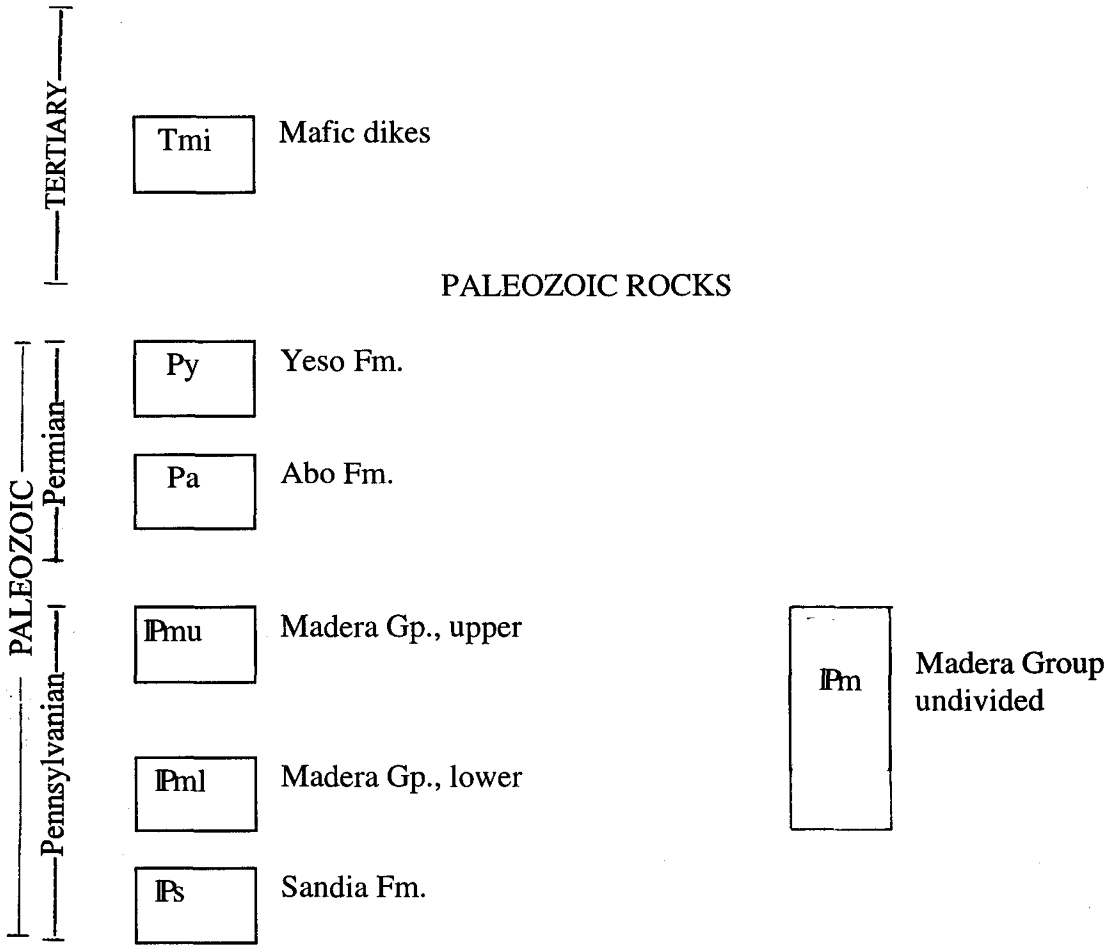
Figure 3. Longitudinal Profile along Hell's Canyon Wash, illustrating inset relations among selected map units.

Mount Washington Quadrangle

Correlation of Pliocene and Quaternary Map Units



MOUNT WASHINGTON QUADRANGLE
Correlation of Tertiary and Late Paleozoic Map Units



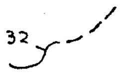
MT WASHINGTON QUADARANGLE

Correlation of Proterozoic Map Units

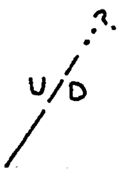
PROTEROZOIC	Middle	Ygd	Granitic to rhyolitic dike
		Xg	Quartz veins
	Early	Xlg	Leucocratic granite
		Xmg	Manzanita granite
		Xbg	Biotite granite
		Xd	Diorite intrusive
		Xmi	Mafic intrusive dikes
		Xs	Schist and phyllite
		Xq	Quartzite
		Xla	Lithic arenite
		Xp	Phyllite and schist
		Xl	Chert and jasper
		Xdt	Dacitic tuff
		Xiv	Intermediate metavolcanic rocks
		Xmv	Mafic metavolcanic rocks

Geologic Map of the Mount Washington 7.5 minute Quadrangle

Explanation of Map Symbols



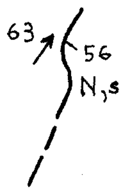
Contact, dashed where approximately located or gradational, dip shown where well exposed.



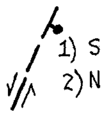
Fault trace, dashed where approximately located, dotted where concealed, queried where uncertain or continuity uncertain. Where dip direction and sense of slip uncertain, U=upthrown side, D=downthrown side.

Normal fault, ball and bar on downthrown hanging wall block.

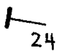
Reverse fault, barb on upthrown hanging wall block.



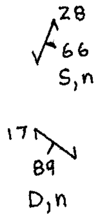
Trace of locally well exposed fault showing dip direction and inclination. Number with arrow indicates plunge and bearing of striations on fault surface. Letters indicate apparent sense of shear based on orientation of slip lines combined with stratigraphic offset or other directional indicators, such as riedel shears and fibre steps (N=normal, R=reverse, D=dextral, S=sinistral; lower case indicates minor component). Striae with rake angles greater than 60°are considered to be essentially dip-slip (ie. normal or reverse).



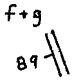
Fault with inferred complex slip history; older sense of slip listed first.



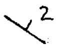
Minor low-angle thrust fault, number and long axis of "T" indicates plunge and bearing of low-angle striations (local shortening direction); most thrusts are essentially dip slip.



Strike and dip of minor high-angle strike-slip fault (upper= sinistral, lower=dextral), plunge and bearing of striations indicated by numbers at half arrow head, sense of slip from reidel shears or local offset of other features (eg. veins, and pebbles).

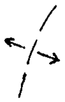


Dip direction and inclination of tensional mineral vein; double line shows trend (approximate strike) mineral fillings include: q=quartz, f=fluorite, g=galena.

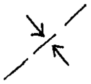


Strike and dip of bedding.

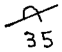
⊕ Horizontal bedding.



Crest line of anticline showing plunge direction, dashed where approximately located.



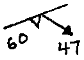
Trough line of syncline showing plunge direction, dashed where approximately located.



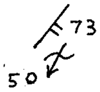
Overturned bedding

Graded bedding, pointing up

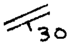
Sl compositional layering in metasediments showing minor fold axis lineation



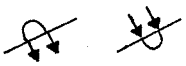
Mylonitic layering in Manzanita granite and metasediments, showing stretching lineation



S2 crenulation cleavage showing F2 fold axis



Minor dike, showing dip and strike



Overturned antiform and synform

Water well, alpha-numeric symbol refers to well listed in Table 1